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Design and Analysis of the Efficiency of a Demonstration Vehicle Propulsion System Utilizing Renewable Energy Sources

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ABSTRACT

Due to the current global energy crisis, particularly the shortage and rising costs of fossil fuels such as oil, there is an increasing focus on renewable energy sources. Electrical energy has emerged as a key alternative, especially when integrated with modern technologies such as electric vehicles (EVs). Among these, solar energy stands out as a clean and sustainable source of electricity that can be effectively used to power EVs. This research aims to design and evaluate the efficiency of a demonstration set for a vehicle propulsion system powered by renewable energy. The objectives of the study are threefold: (1) to provide an electrical power source for the demonstration kit, (2) to implement a steering control system using a servo motor and assess its performance under conditions with and without a PWM signal, and (3) to evaluate the effectiveness of a custom-designed charging system. The design and performance analysis of this demonstration kit serve as a practical tool for studying the application of renewable energy in transportation. It simulates real-world vehicle operation, promoting an understanding of energy systems, control mechanisms, and electrical integration. This demonstration model is also intended to serve as an educational aid for students and researchers interested in sustainable vehicle technology. By providing hands-on experience, the project supports learning about the components and functionality of electric propulsion systems in a renewable energy context.

Keywords: charging system; demonstration kit; renewable energy; PWM signal; vehicle propulsion system

1. Introduction

The global energy crisis, particularly the shortage and rising cost of fossil fuels such as oil, has compelled many nations to prioritize the development and utilization of alternative energy sources. Among these, electrical energy plays a crucial role, as it can be applied not only for household electricity consumption but also as a sustainable power source for transportation systems [1]. In contemporary society, technology has become an indispensable factor in human life, significantly influencing and transforming daily living toward greater modernity and convenience. One prominent technological advancement that simultaneously enhances efficiency and reduces reliance on fossil fuels is the electric vehicle (EV), which constitutes a critical factor in consumer decision-making regarding automobile purchases [2].

Furthermore, solar energy, harnessed through photovoltaic (PV) systems, represents another form of electrical energy applicable to EVs. This energy source is widely recognized as clean and environmentally sustainable, as it produces no greenhouse gas emissions in contrast to conventional fossil-based energy systems [3,4].

The adoption of electric vehicles (EVs) is expected to extend the depletion timeline of the world's oil reserves, which are projected to last for approximately 47 more years [5] (https://www.worldometers.info/oil/). From the perspective of automobile usage, it must be acknowledged that EVs, in addition to being a more advanced technology, also require less complex maintenance and incur lower overall costs compared to conventional vehicles. The maintenance of EVs is generally considered "dry maintenance," as they do not require engine oil and thus eliminate the need for oil changes or waste fluid disposal. Moreover, EVs operate solely on electricity, as they are not equipped with internal combustion engines. Consequently, charging the battery becomes the sole process for supplying and managing the vehicle's power system. Therefore, if electricity derived from clean and renewable sources, such as solar energy through photovoltaic (PV) cells, can be employed for battery charging, EVs would represent an even more sustainable transportation solution [6].

Research and development in the field of prototype electric vehicles has expanded considerably, leading to various design approaches. For instance, one design features a four-wheel vehicle with rear-wheel drive powered by a Brushless DC Motor (BLDC) [7]. This configuration utilizes lithium-iron-phosphate batteries as the primary energy source and incorporates a power transmission system featuring chains and gear reduction units, enabling adjustable speed control. Another example involves the design and construction of an electric tricycle, in which the two front wheels are driven by brushless DC motors. In this system, MOSFETs are utilized as power-switching devices operating at a frequency of 10 kHz, while motor control is achieved through a six-quadrant control circuit [8].

Additionally, research has also been conducted on the development of multipurpose solar-powered electric vehicles, which can serve diverse functions, including the transportation of goods and acting as auxiliary energy sources for household electrical appliances [9]. Generally, the operation of electric vehicles relies on DC motors for propulsion, rather than conventional internal combustion engines, with batteries serving as the primary power source. Numerous studies have particularly focused on optimizing the speed control of electric vehicles to meet desired performance under varying load conditions [10].

Therefore, the researchers have clearly recognized the growing trend in the adoption of electric vehicle innovations and, consequently, have become interested in studying the development and design of an efficient demonstration vehicle propulsion system utilizing renewable energy sources. The objective of this study is to evaluate the performance of the demonstration system as both a learning tool and a practical simulation platform for real-world applications. Furthermore, the demonstration system serves as an educational model for understanding various subsystems.

The study is divided into three main components:

- The provision of an electrical energy source for the demonstration system.
- The design of a motion control system for a servo motor, operated via a PS2 joystick Arduino controller, with testing conducted under two conditions:
    - (a) when a PWM signal is applied and when it is not applied, and
    - (b) when tested on an inclined surface with a defined slope.
- The evaluation of the performance of the charging system powered by renewable energy.

2. Research Methods

The research process is divided into 3 phases: (1) collecting and studying preliminary data, (2) creating and designing a demonstration kit for driving vehicles using renewable energy, and (3) testing the efficiency of the experimental kit. The research methods are as follows:

2.1 Gathering and Studying Preliminary Data

Data were collected from research documents, books, academic articles, internet data, and other relevant sources to gather information on the design and construction of a demonstration kit for electric vehicle propulsion, servo motors, batteries, solar cells, H-Bridge charger circuits, and JoyStick PS2 Arduino, as well as other data that could be applied to this research (Fig. 1).

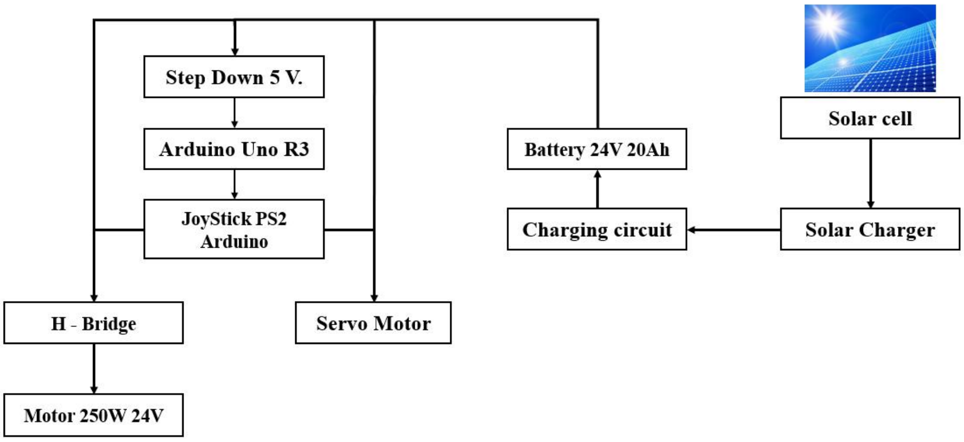

Fig. 1. Overview of the research methodology.

2.2 Creation and Design of a Demonstration Set for Driving Vehicles using Renewable Energy

2.2.1 Drive system design process

In this step, we designed a 250W, 24V motor drive system using an H-Bridge circuit connected to an Arduino Uno R3 board. We used an Arduino JoyStick PS2 to control the motor's forward and reverse rotation (Fig. 2).

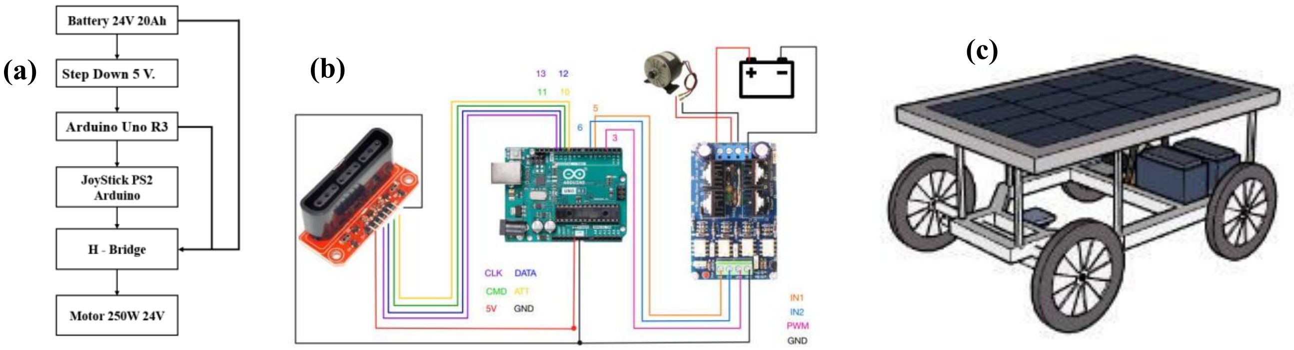

Fig. 2. Drive design process (a) flowchart, (b) connection of 250W 24V motor drive, and (c) drive demonstration structure

2.2.2 Battery size selection by considering:

Current capacity in the absence of sunlight/day (Eq. 1).

$$\text{Battery size for 1 day without sunlight} = 15.80\ \text{Ah} \times 1\ \text{d} = 15.80\ \text{Ah} \quad (1)$$

Percentage of battery discharge (Eq. 2).

$$\text{Discharging limit} = 80\%\ \text{of capacity} \quad (2)$$

Find the required battery size (Eq. 3).

$$\text{Battery size} = 15.80\ \text{Ah}/0.80 = 19.75\ \text{Ah} \quad (3)$$

2.2.3 Steering control design process

A 24-volt servo motor drive is connected to control the right and left turns of the drive system demonstration kit. The design utilizes an Arduino Uno R3 board to transmit signals to the JoyStick PS2 Arduino, which in turn controls the steering direction (Fig. 3).

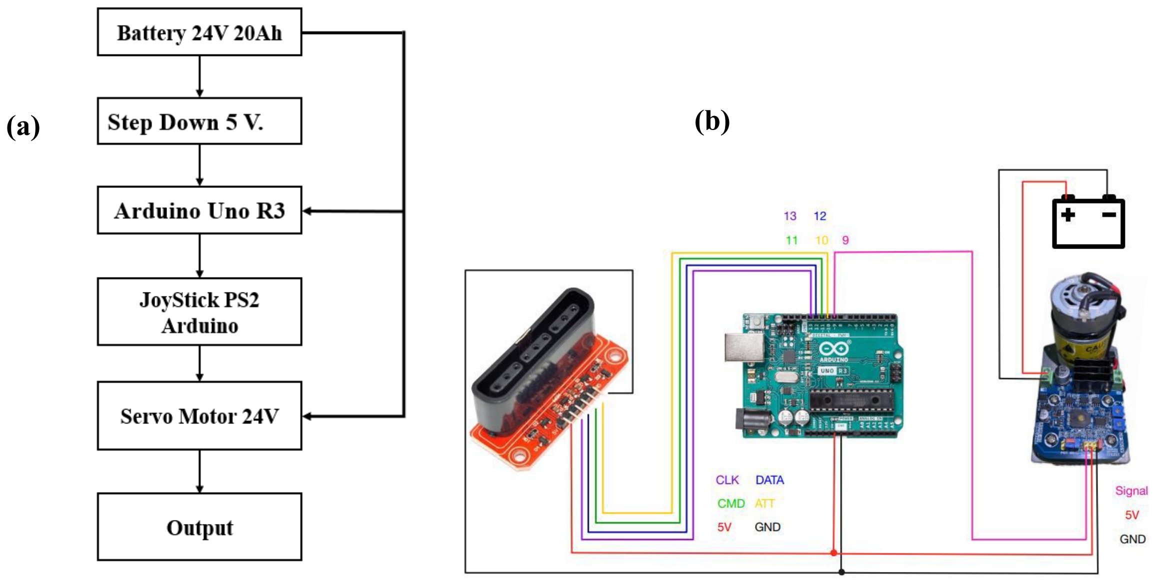

Fig. 3. Steering system design (a) flowchart of steering system design steps, and (b) steering system control circuit

2.2.4 Charging system design

The battery charging circuit was designed to charge the battery from a 220 VAC system through a designed charging circuit and store it in a 24-volt battery.

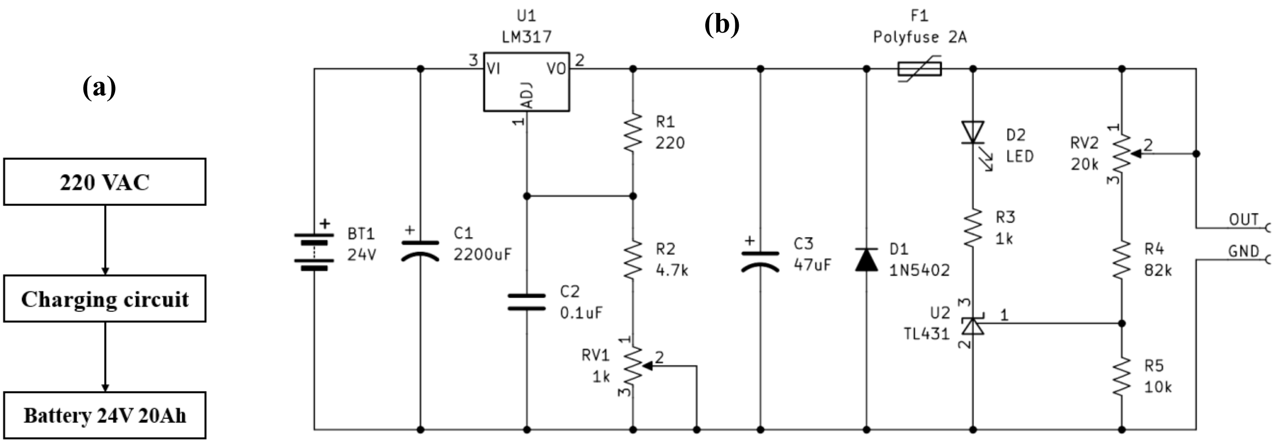

Fig. 4: Design of an AC charging system, (a) flowchart of the charging system design process, and (b) charging system circuit.

The solar cell charging circuit is shown in Fig. 5.

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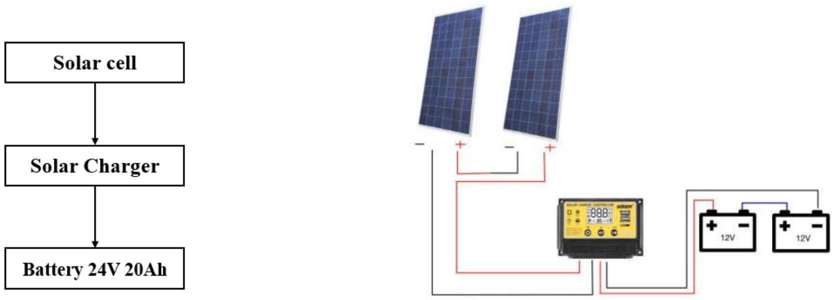

(a) (b)

Fig. 5: Solar cell charging system design (a) flowchart of the solar cell charging circuit, and (b) design of the solar cell charging circuit

Steps for selecting the size of a solar cell panel by calculating the number of solar cell modules:

When: Total load size: DC load demand = 316.2 Wh

System voltage (V_L) = 24V

Calculate the required current using Eq. 4.

$$\text{Load current demand } I'_L = Dc\frac{Load}{V_L} = 13.17\ Ah \tag{4}$$

Calculate the current allowance due to losses. This can be found as Eq. 5.

Compensation for system losses = 20% of load current demand

$$\text{Overall current demand} = I'_L \times 20\% \text{ of load current demand} \tag{5}$$

2.3 Performance Testing of the Experimental Kit

This evaluation assesses the performance of a renewable energy-powered demonstration vehicle and was conducted as follows:

(a) Design of the servo motor steering control system to control steering using a PS2 Arduino joystick.
(b) Voltage control testing with a PWM signal input.
(c) Voltage control testing without a PWM signal input.
(d) Testing on a sloped area with a steep slope.

The resistance force is the force that acts opposite to the transmitted force, and the power from the motor used for driving may not be fully utilized due to losses in the transmission [11]. In this research, the author is interested in considering the resistance force from the slope.

The calculation of slope resistance is done by breaking the force into two forces: the force perpendicular to the slope surface and the force parallel to the motion of the train. The force parallel to the train's motion can be calculated to find the slope resistance force using Equation [12].

$$F_g = mg\sin\theta \tag{6}$$

Where F_g is the slope resistance [N]
m is the weight of the train [kg]
g is the force of gravity [m/s2]
G is the percentage slope [%]

3. Research Results

From the development and design of an efficient demonstration vehicle propulsion system utilizing renewable energy sources, the research results regarding testing the motor drive system and other components are presented as follows.

3.1 Servo Motor Drive Test for Steering Direction

From the test, it was found that when a PWM signal was applied to the servo motor shaft to turn left and right 10 times, the test results showed that the servo motor rotated in the commanded direction all 10 times. During the test of the PWM signal input between the servo motor and the joystick PS2 Arduino, it was observed that when no PWM signal was applied, the servo shaft angle was 90 degrees, with the joystick PS2 Arduino reading at 128. When the signal for full right turn was applied, the servo shaft angle was 180 degrees, with the joystick PS2 Arduino reading at 255. When the signal for full left turn was applied, the servo shaft angle and the joystick PS2 Arduino reading were both 0.

Table 1: PWM signal input test results

Signal input	Servo axis position	JoyStick PS2 Ardino	Steering test
No signal input	90 degrees	128	-
Enter the maximum right turn signal	180 degrees	255	Work according to the number of times tested
Enter the maximum left turn signal	0 degrees	0	Work according to the number of times tested

3.2 Motor Drive Testing

A 250-watt, 24-volt motor was used for forward and reverse driving. Motor rotation speed and output voltage values were tested at various times as shown in Fig. 6.

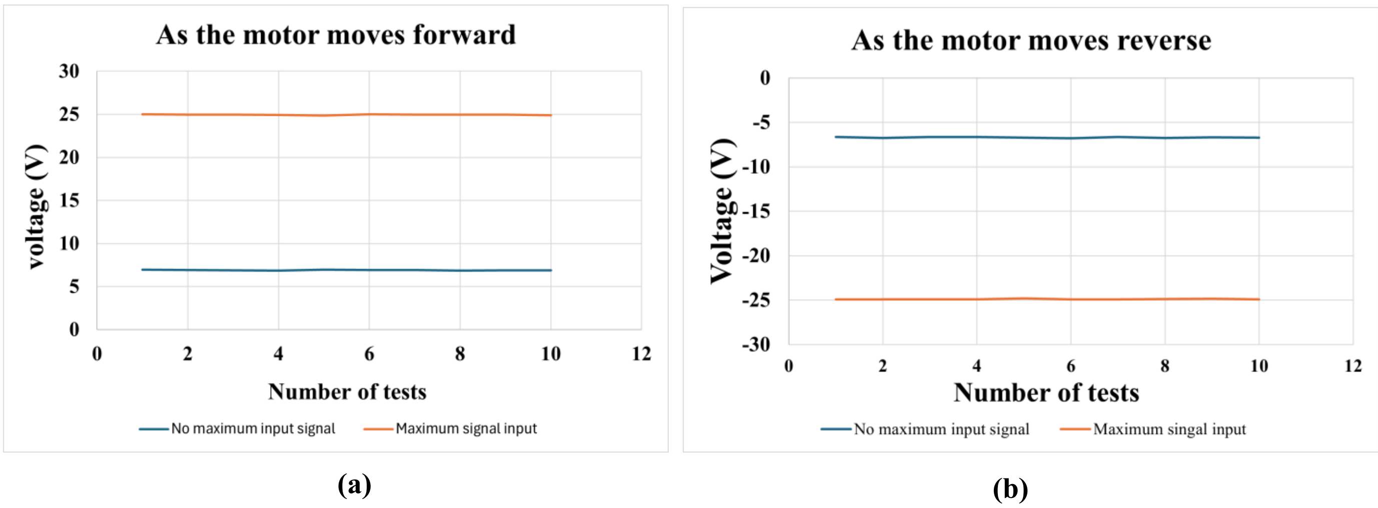

Fig.6 The graph shows the relationship between the PWM signal input and the voltage, (a) as the motor moves forward, and (b) as the motor moves reverse

From the experimental investigation, a 250-watt, 24-volt motor was examined to evaluate its forward and reverse rotational performance under pulse-width modulation (PWM) control. The results indicated that when PWM signals were applied to drive the motor forward and reverse for a total of ten cycles, the motor successfully completed all forward and reverse rotations as commanded. Voltage measurements were conducted under two operating conditions: without maximum PWM input and with maximum PWM input. In the absence of maximum PWM input, the average voltage during forward rotation was 6.91 V, whereas during reverse rotation the average voltage was -6.68 V. Conversely, under maximum PWM input, the average voltage during forward rotation was 24.88 V, while during reverse

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rotation the average voltage was -24.89 V. These findings confirm the reliable bidirectional operation of the 250-watt, 24-volt motor under PWM control, with measured voltages corresponding appropriately to the applied signal conditions.

3.3 Real-world Test Results of the Propulsion Demonstrator

The electric vehicle propulsion demonstration unit was run on a 50-meter field. The demonstration was conducted to move forward, backward, left, and right, resulting in the following test results.

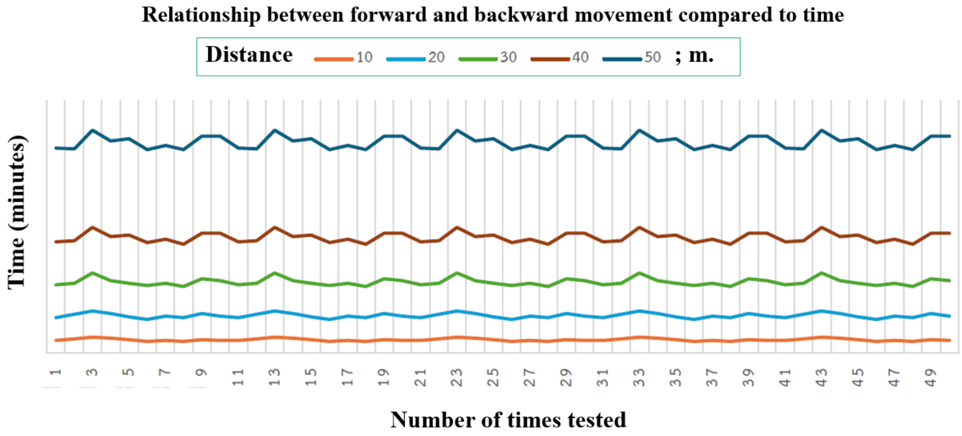

Fig. 7 Relationship between forward and backward movements compared time.

From the test, the vehicle demonstration prototype was evaluated in an actual field trial conducted on a football field with a length of 50 meters. The experiment involved testing forward movement, backward movement, left turn, and right turn. The results indicated that the travel times for each trial were relatively consistent. At 10 meters, the travel time was approximately 0.14–0.19 minutes; at 20 meters, approximately 0.26–0.31 minutes; at 30 meters, approximately 0.37–0.45 minutes; at 40 meters, approximately 0.50–0.57 minutes; and at 50 meters, approximately 1.09–1.15 minutes.

3.4 Testing on Inclined Surfaces

The experimental evaluation of the vehicle demonstration prototype was conducted on an inclined surface to assess its capability for uphill climbing. A total of 50 trials were performed, during which the prototype was tested for uphill movement with assisted driving speed. The results revealed that the demonstration unit could climb a maximum slope angle of 24°.

3.5 Charging Efficiency Test

The charging performance of the battery for the electric vehicle propulsion demonstration system was evaluated using two 25-watt solar panels connected in series. The experiment involved measuring the charging current supplied to the battery from the solar panels at different time intervals, as well as recording the corresponding increases in battery voltage over each period. The results are presented as follows:

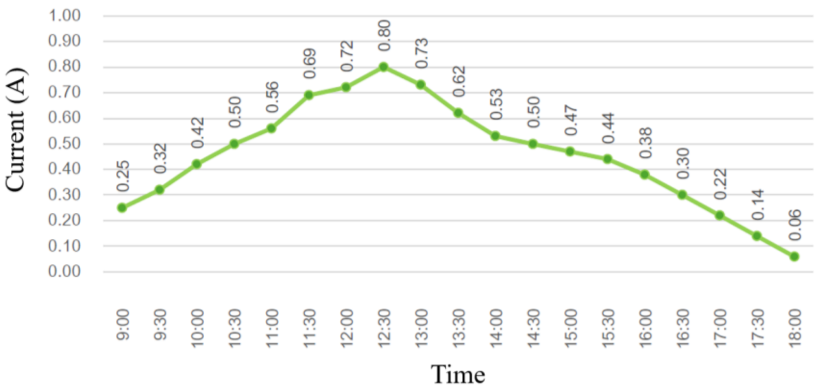

Fig. 8: The graph shows the battery charging value from the solar panels at different times

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From the battery charging test of the electric vehicle propulsion demonstration system using two 25-watt solar panels connected in series, it was observed that the charging performance varied across different time intervals. The initial charging current was recorded at 0.25 A, and subsequent measurements were taken every 30 minutes. The charging current increased progressively with each interval, reaching its maximum during periods of high solar irradiance. As time progressed, the charging current gradually decreased, corresponding to the reduction in solar intensity, until eventually reaching 0.06 A—an extremely low value, indicating little to no effective charging of the battery.

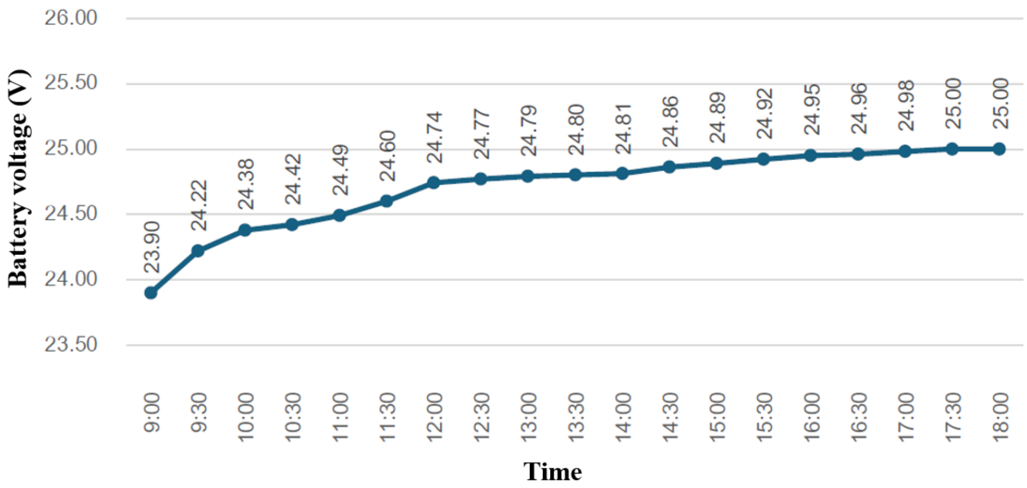

Fig. 9: Graph showing the increase in battery voltage over time

From the battery charging experiment of the electric vehicle propulsion demonstration system using two 25-watt solar panels connected in series, it was observed that at the initial charging stage, the charging current was 0.25 A with a corresponding battery voltage of 23.90 V. Voltage measurements were then recorded at 30-minute intervals, showing a gradual increase in battery voltage over time. At the final stage, the charging current decreased to 0.06 A, indicating that no effective current was being supplied to the battery, and the battery voltage reached 25 V. The total charging time required to fully charge the battery was approximately 9 hours.

4. Conclusion

This study focused on the design and performance evaluation of a demonstration system for vehicle propulsion using renewable energy. The steering mechanism, controlled by a servo motor and interfaced with a joystick PS2 Arduino, was tested for angular response. The results showed that without an input signal, the servo motor maintained a neutral angle of 90°, corresponding to a joystick reading of 128. Full right and full left signals resulted in servo angles of 180° and 0°, respectively, with corresponding joystick readings of 255 and 0. Voltage measurements under PWM signal conditions indicated that, without maximum signal input, the motor voltage averaged 6.91 V in the forward direction and -6.68 V in reverse. Under maximum signal input, the motor voltage increased to an average of 24.88 V forward and -24.89 V reverse. The system was further tested on an inclined surface, demonstrating stable propulsion up to a slope of 24°. Battery charging performance using two 25-watt solar panels connected in series was also evaluated. The initial battery voltage was 23.90 V with a charging current of 0.25 A. Charging efficiency improved with higher solar irradiance, with the maximum observed current reaching 0.80 A. The results confirm that the demonstration system is suitable as a prototype for developing renewable energy vehicle propulsion systems and can serve as an effective educational tool for learning and experimentation.

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